REPORT TO THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Research Grant NsG-502

Neurophysiological and Behavioral Studies of Chimpanzees,

Including Establishment of a Group of

Implanted Animals Suitable for Space Flight

For the Two Semi-Annual Periods

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This report covers a period of transition in the colony arrangements. Of the six original animals acquired more than three years ago, four have now been removed from the colony, by reason of growth to weights beyond those reasonable for flight experiments, and for reasons of difficulty in control and handling. Two of the four animals were sacrificed for histological purposes as a check on the accuracy of our recently published Stereotaxic Atlas of the Chimpanzee Brain. New animals are being acquired in the 12-15 pound range, and it is anticipated that they will have a useful colony life of approximately four years, based on weight and growth curves acquired on the original series. With the occupancy of the laboratories in the new NASA campus Space Sciences Center due at the end of December, 1965, it is anticipated that some aspects of the colony will be housed there, although, as explained below, the need for computer control of new behavioral test procedures requires retention of animals in training in the present location in the Brain Research Institute.

Studies have been completed in computer analysis of EEG patterns during behavioral task performance with tic-tac-toe procedures, and with disclosure of remarkably constant shifts in EEG patterns during the discriminative performances. Evaluation of a small biotelemetry system in the freely moving animal has indicated complete feasibility for recording continuously or intermittently over a period of many weeks.

With the Apollo Applications Program now launched, our attention is being directed to the design of a long-duration primate experiment, with intensive instrumentation in two animals, and arranged to provide complementary information, on basic states and limits of performance capabilities beyond tests now planned in the NASA Biosatellite Program. Present effort and future plans are being directed to the collection of base-line and flight feasibility data under this grant for such an experiment.

A. Computer Analysis of EEG Patterns in Alerted States and during Visual Task Performance.

Using the tic-tac-toe procedure described in previous reports, EEG activity was simultaneously recorded from surface leads, and from deep structures, including the hippocampus and amygdala in the temporal lobe, and in the mid-brain reticular formation. Computer analysis by Dr. D. O. Walter and Dr. J. Hanley involved a number of newly developed procedures, which have been evaluated in other NASA supported research, including pattern-recognition techniques applied to data specially collected on 50 Apollo astronaut candidates during perception and learning task performance. These techniques have involved the development of new forms of spectral analysis, and most recently, application of pattern recognition techniques to the output of these initial spectral analyses. It should be emphasized that in similar applications to scalp recordings in the astronaut candidates, the technique has proven its ability to make fine distinctions between EEG patterns accompanying progressively more difficult task performances, both within and between individuals in the group. The pattern recognition method involves a discriminant analysis of parameters calculated in the initial spectral analyses.

Results from one of the animals tested in this way will be presented here in some detail. The spectral analyses included calculation of auto-spectral densities in the range from 1 to 30 cycles per second, with spectral windows 1 cycle per second wide throughout this range. Cross-spectra were calculated between pairs of leads, based on records from the left and right amygdala, the left and right hippocampus, the right rostral mid-brain reticular formation and from cortical areas in the fronto-central, centro-parietal and parieto-occipital regions. In the course of these cross-spectral analyses, coherence functions (which provide a measure of linear predictability between the pairs of leads), phase angles and spectral widths in any particular "window" of the spectral analysis were all calculated. On completion of these basic calculations, a discriminant analysis was performed, with preparation of a typical matrix for variables in each brain wave lead. From 38 variables covering all leads, the computer selected three as most indicative of changing states in the focusing of attention in the task performance. They were the increase in density across the beta wave band (from 13 to 25 cycles per second) in the fronto-central surface brain lead, the shift in the mean theta frequency (the band from 4 to 7 cycles per second) in the amygdala, and the shift in the main theta frequency in the hippocampus. Additional factors which contributed to the differentiation of the states were the intensity of the theta wave activity in the amygdala and also in the hippocampus, and bandwidth of the theta activity in the amygdala and hippocampus. These results are summarized in the following table, and are the first quantified analyses of this type interrelating surface and deep-brain structures in their patterned activity in alerted states and during task performance. The findings strikingly supported classic hypotheses that the deep temporal lobe regions in particular are most sensitive to fine shifts in the state of consciousness, and it would be anticipated that analysis of flight data gathered in comparable circumstances would sensitively reveal any subtle but important shifts in states of alertness in prolonged space flight.

Discriminant Selected by Computer	Intertrial Records		Records During Visual Task Performance	
	Mean	S.D.	Mean	S.D.
Total Spectral Energy in Beta Band in Fronto-Central Lead	25.55	5.81	35.60	8.80
Mean Theta Frequency in Amygdaloid Lead	5.27	0.244	4.97	0.267
Mean Theta Frequency in Hippocampal Lead	5.12	0.223	4.85	0.183
DIFFERENCES NOTED BUT NOT UTILIZED BY COMPUTER IN PATTERN RECOGNITION				
	Mean	S.D.	Mean	S.D.
Mean Theta Intensity in Amygdaloid Lead	498.3	149.7	572.4	131.3
Mean Theta Intensity in Hippocampal Lead	304.7	135.2	359.9	106.1
Bandwidth in Theta Band in Amygdaloid Lead	2.46	0.555	2.27	0.519
Bandwidth in Theta Band in Hippocampal Lead	2.60	0.595	2.06	0.347

B. Development of New Training Procedures Desirable for Psychophysiological Testing in Prolonged Space Flight.

Although the tic-tac-toe procedure outlined above affords a simple medium to test levels of visual integration of a high order, and also can be established as a competetive situation between a pair of animals, it was considered to be less suited to space flight problems than a "Matching to Successive Sample Task" (MSST). This technique has been developed by Weiskrantz and his colleagues for the monkey at Cambridge, England, and in the form developed here, appears to sustain the chimpanzee's attention in a fashion allowing adequate attention spans in appropriate neurophysiological recordings.

The display consists of a transluscent sample key located centrally above a row of 12 similar response keys. Upon the faces of each key can be projected one of 12 possible symbols. In this task, each trial consists of (a) a sample, (b) a delay, (c) response periods. The trials are separated by a variable "time-out" interval.

1. Sample period

Following presentation of a cue tone, from one to twelve different symbols appear randomly and successively upon the sample key, provided the animal depresses the sample key during a designated period for each symbol. If it fails to respond to each sample during this period, then the symbol is "blanked out". No further symbols will appear and the trial will be entered as void. When the predetermined number of symbols have been "turned on" by the subject, a second tone is presented, and a delay period begins.

2. Delay period

During the variable delay period all keys remain blank until the commencement of the response epoch.

3. Response period

At the onset of the response period, the same symbols presented during the sample period appear in random but adjacent positions at the center of the response display (i.e., they are centrally located when less than 12 symbols are being displayed). The animal is required during the finite overall response period to successively depress each symbol in the same order as they had been pressed (i.e., were presented) during the sample period. Following each correct successive response a reinforcement tone is presented. If an incorrect symbol is depressed, the response display will "blank out" and a trial void period will commence. If all symbols are depressed in the correct order, reinforcement with a banana pellet or candy is provided. Reinforcement is thus on a 1:1 ratio for each correct trial.

This procedure has been developed under control by the SDS 930 digital computer currently installed in the laboratory, and the necessary programs have been written and thoroughly tested, so that the requirement for a small special-purpose flight computer to program this task has been found feasible.

The task thus provides three discrete epochs for analysis:
1. Information acquisition
2. Short-term memory storage
3. Response

Moreover, the task will lend itself readily to comparative studies of performance in monkey, chimpanzee, and man.

C. Evaluation of Long-term Biotelemetry of Brain Activity in the Freely Moving and Performing Chimpanzee.

Feasibility has been shown in other studies in this laboratory to telemeter the chimpanzee EEG with a multi-channel system using FM subcarriers. Although this system has been reduced in physical size to packs worn in a flight type suit, the suit itself constituted a modification not desirable in a colony environment.

For this reason, we have developed a smaller single and dual channel micro-miniature device that attaches directly to the animal's head plugs, and thus becomes integral with the implant system. Although this technique, using simple frequency-modulated oscillators, has been proven for a maximum of only two channels, the data so gathered has been of substantial physiologic interest, particularly in the studies of performance, and unrestrained sleep. Since the chimpanzee customarily sleeps in a recumbent position, attachment of head cables is impractical without substantial restraint to the animal, with consequent interference with sleep patterns over an adjustment period of many nights.

This system has provided continuous recording of EEG activity for as long as two weeks without battery replacements. Since a configuration with minimal physical restraint is viewed as a vital part of the experimental protocol for at least one chimpanzee in our proposed Apollo Applications Program Experiment, use of such systems of local telemetry in the spacecraft will be of vital importance. We are currently evaluating methods of recharging batteries by use of radio frequency systems, in view of the length of the proposed flight in relation to anticipated battery life.

Since use of the system does not involve an initial approach to the animal, it has been possible to record EEG patterns in circumstances of sleep and wakefulness that are traditionally disrupted by the use of cable attachments.